

**USARIEM TECHNICAL REPORT T03-13**

**ENDURANCE TIME IN THE SELF-CONTAINED TOXIC ENVIRONMENT  
PROTECTIVE OUTFIT (STEPO) WITH PERSONAL ICE-COOLED MICROCLIMATE  
COOLING SYSTEM (PICS) IN THREE ENVIRONMENTS**

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Human subjects participated in this study after giving their free and informed voluntary consent. The investigators have adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of Federal Law 45 CFR Part 46.

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## BACKGROUND

This study of the Self-Contained Toxic Environment Protective Outfit (STEPO) with the Personal Ice-Cooled Microclimate Cooling System (PICS) in three environments was conducted in September 2002 at the request of Project Manager – Soldier Systems, Product Manager – Soldier Equipment (PM-Soldier), Ft. Belvoir, VA. PM-Soldier was addressing the needs of the STEPO/PICS users for guidance on work times up to 4 hours. A 1999 study of this STEPO/PICS system demonstrated that 4-hr work times were not safe for workers in a 38°C (100°F) environment. Using the same testing format of repeated cycles of 10 min rest and 20 min of treadmill walking, eliciting an overall moderate energy cost of 300-350 Watts, this study looked at the system in three less stressful environments: HOT 32.2°C (90°F) / 30% rh, MODERATE 23.9°C (75°F) / 40% rh, and COOL 15.6°C (60°F) / 50% rh, to ascertain endurance times in each of these environments.

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## EXECUTIVE SUMMARY

During September 2002 this laboratory study of the Self Contained Toxic Environment Protective Outfit (STEPO) with the Personal Ice-Cooled Microclimate Cooling System (PICS) was conducted to address STEPO user needs for a 4-hr work time. The U.S. Army has fielded the STEPO system as its highest level of personal protective equipment for use in highly toxic, unknown, or oxygen deficient environments that pose an immediate danger to life and health. This system completely encapsulates the wearer from the environment in an impermeable, one-piece outer garment with an airtight closure. A backpack rebreather carried under the STEPO outer shell provides respiratory protection, while a long sleeved upper-body cooling garment worn next to the skin, circulates cooled water over the skin surface to provide cooling. The PICS cooled water is provided from a small ice-chilled reservoir carried by the user. A previous study and subsequent Health Hazard Assessment of the STEPO and PICS systems determined that a 4-hr work time was not safe for workers in a 38°C (100°F) environment, and recommendations were made for continuous work times of no more than 2 hr, to maintain core temperatures below 39.0°C. The current study evaluated heat strain and endurance time in volunteers testing in STEPO with PICS in three less stressful environments (all with minimal wind speed  $\leq$ 2mph): HOT - dry bulb temperature ( $T_{db}$ ) 32.2°C (90°F) / 30% rh, WBGT 23.4°C (74°F); MODERATE -  $T_{db}$  23.9°C (75°F) / 40% rh, WBGT 18.1°C (64.5°F); and COOL -  $T_{db}$  15.6°C (60°F) / 50% rh, WBGT 11.8°C (53°F). Prior to the STEPO clothing tests, five healthy soldier volunteers completed a 7-day exercise heat acclimation program of 2 hr/day cycles of 10 min rest and 50 min treadmill walking (3 or 3.5 mph / 4% grade) wearing physical training (PT) clothes (shorts, t-shirt, athletic shoes and socks) in a 35°C (95°F) / 50% rh environment. They then completed testing in STEPO with PICS in each of the three test conditions. Rectal temperature, skin temperature, heart rate, and body weight were measured. Percent dehydration and physiological strain index (PSI) were calculated from the measured data. Subjective measures of perceived exertion and thermal strain were also collected. Testing consisted of repeated cycles of 10-min rest and 20-min treadmill walking at 2 mph / 0% grade for up to 4 hr. Test subjects were tested in one condition per day, with at least one day off between tests. Endurance times averaged (mean (SD)) 178 (57) min, 223 (26) min, and 228 (27) min in the HOT, MODERATE, and COOL environments, respectively. Though two of five volunteers were able to complete 4 hr in the HOT environment, they were significantly dehydrated (3-3.5%), and their core temperatures were 38.89°C and 38.25°C, indicating significant heat strain. Three of five subjects completed 4 hr in the MODERATE environment, and four of five completed 4 hr in the COOL environment. The calculated PSI indicated moderate to very high heat strain in the HOT test, low to moderate strain in the MODERATE test, and low strain for the COOL test. All the volunteers said that the system felt heavy and that they were tired following each of their tests. These data support a safe work time of 2.5 hours at 90°F and 4-hr work times at 75°F and 60°F.

## INTRODUCTION

In September 2002, a laboratory study of the Self-Contained Toxic Environment Protective Outfit (STEPO) was conducted to address the needs of STEPO users to work for up to 4 hrs at a time in the STEPO system with microclimate cooling provided by the Personal Ice Cooling System (PICS). A 1999 study (2) showed that this same STEPO with PICS system did not allow 4-hr work times for volunteers testing in a 38°C (100°F) environment, a worst-case work scenario for STEPO users. In the current study we tested the STEPO with PICS system in three cooler environments. This report is of that 2002 STEPO/PICS study.

The U.S. Army has fielded the STEPO system as its highest level of personal protective equipment for use in highly toxic, unknown or oxygen deficient environments that pose an "immediate danger to life and health" (IDLH). This system completely encapsulates the wearer from the environment in an impermeable, one-piece outer garment with an airtight closure. A re-breather with a CO<sub>2</sub> scrubber, carried as a backpack under the STEPO outer shell, provides respiratory protection. A long-sleeved upper-body cooling garment worn next to the skin circulates cooled water over the skin surface to provide convective cooling. In the PICS, cooled water is provided from a small, ice-chilled reservoir carried by the user.

STEPO was designed in response to safety limits for allowable exposure to chemical warfare agents developed by the Occupational Safety and Health Administration (OSHA). STEPO was designed to meet OSHA standards for Level A Personal Protective Equipment, when the greatest level of skin, respiratory, and eye protection is required (10). STEPO is currently fielded for both civilian and military personnel working at Chemical Weapons Arsenals, and in Explosive Ordnance Disposal. Technical Escort personnel may also be using the STEPO system.

STEPO is designed as a 4-hr system from donning to doffing, with the limiting feature being the self-contained CO<sub>2</sub> scrubber, re-breather subsystem. However, the STEPO Requirements Document also states that users should be able to perform duties in STEPO for 4 hrs in environments with ambient temperatures up to 38°C (100°F). Previous experiments with soldiers performing exercise at 38°C, 30% relative humidity (rh) while wearing STEPO cooled with PICS indicated that it is unlikely that soldiers could perform their duties for much more than 90 min in this environment (2). The Health Hazard Assessment Report (7) provided by the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) and derived from USARIEM test data and report of the 1999 STEPO study (2), recommended that there should be a maximum continuous work time of 2-hrs in STEPO with the upper body PICS cooling during work in a 38°C (100°F) environment.

The user communities for STEPO require up to 4 hours of STEPO wear to perform certain of their missions. Because 38°C (100°F) is a worst-case condition for STEPO use, the users requested development of potential work-time versus ambient temperature guidelines to determine if longer missions are possible at lower

temperatures. Current predictive models are unable to predict endurance or stay times for the combination of a cooling garment worn inside impermeable clothing. For this reason it was recommended that human exercise-heat stress tests be conducted to collect data for development of these guidelines. Ambient temperatures of 15.6°C (60°F), 23.9°C (75°F), and 32.2°C (90°F) were chosen for the current study because they provide a broad range of cooler temperatures in which the PICS should be beneficial in reducing heat strain, while significant differences in physiological responses may be observed. Data from these three test environments, combined with the previously collected data at 38°C (100°F), will allow use of the data for developing work time guidelines from prediction modeling.

## METHODS

### TEST VOLUNTEERS

Eight male soldier volunteers from the Headquarters & Headquarters Detachment at Natick Soldier Systems Center (Natick, MA), or from the National Guard's Weapons of Mass Destruction 1<sup>st</sup> Civil Support Team (Natick, MA) were recruited to participate as test subjects in this study. All procedures and risks were explained both orally and in writing prior to obtaining informed consent from the volunteers. A medical officer cleared volunteers as healthy after a physical exam and review of medical history.

Five of the eight volunteers completed all the STEPO tests for this study. Only data from those 5 volunteer test subjects will be presented in this report. The subjects' anthropometric characteristics are shown in Table 1. These characteristics represent men of average size, from their early 20's to 30 years of age. Three of the five test subjects were the National Guard soldiers (Subjects 1,2,3). They were experienced at working in similar protective clothing as the STEPO. The other two subjects were soldiers stationed at the Natick Soldier Systems Center (Subjects 6,7). Beyond routine Army training, they were not experienced in working in protective clothing, and they had no experience working in protective clothing similar to the STEPO.

**Table 1. Anthropometric Characteristics (n=5)**

Subject #	Age (yrs)	Height (cm)	Weight (kg)	BSA* (m <sup>2</sup> )	Fat** (%)
1	30	182.4	99.8	2.21	24
2	27	175.6	73.0	1.89	19
3	30	172.3	66.6	1.79	16
6	23	180.5	83.6	2.04	19
7	21	169.5	69.8	1.80	23
Mean (SD)	26 (4)	176.1 (5.4)	78.6 (13.5)	1.95 (0.18)	20.2 (3.3)

\*Body Surface Area (BSA) in meters<sup>2</sup> = Wt (kg)<sup>0.425</sup> x Ht (cm)<sup>0.725</sup> x .007184

\*\*Percent Body Fat estimated from four skinfold measurements (5)

## PRELIMINARY MEASUREMENTS AND HEAT ACCLIMATION

Once cleared to participate, the test subjects were size-fitted for the STEPO and PICS undergarment. They then participated in two familiarization sessions on two separate days. The familiarization environment was room temperature (20°-25°C or 68°-77°F). The first familiarization session consisted of dressing in the PICS, rebreather and STEPO systems and walking on a treadmill (2mph/0%grade) for 15 minutes. For the second session, subjects again donned the PICS, rebreather and STEPO systems, this time with the mask carried but not worn and with the STEPO hood unzipped to allow for collection of expired air samples. The expired air samples were collected at the end of a 15-min treadmill walk (2mph/0%grade), and again following 15 min of seated rest. The expired air was collected in Douglas bags and analyzed via open circuit spirometry (8) to report the metabolic rates, shown in Table 2. The metabolic rates were used to quantify the overall energy cost of working in STEPO during the rest/exercise cycles of this study, to show that they were comparable to the energy costs of those actually working in STEPO. The desired time-weighted metabolic rate of approximately 300 Watts (W) had been determined in earlier STEPO field studies of Depot and EOD workers participating in simulated mission scenarios (3).

Following the familiarization sessions, the test subjects participated in a 7-day (consecutive weekdays) exercise heat acclimation process. Acclimation was designed to better prepare the subjects for the STEPO tests, and to insure that their thermoregulatory status did not change during testing (14). Each day of acclimation consisted of 120 minutes of testing in the environmental chamber. The acclimation environment was 35°C (95°F) / 50% rh with minimal wind ( $\leq 2$ mph). Subjects, dressed in shorts, t-shirt, socks and athletic shoes, repeated 2 cycles of 10-min seated rest and 50-min treadmill walking at 3.5 mph, 4% grade. Throughout and following each acclimation session, subjects were encouraged to drink water or a commercial sport drink to maintain hydration; though consumption was *ad libitum*. Pre- and post-test weights were measured to document hydration status, and water and commercial sport drinks were provided to insure subjects were adequately hydrated (within  $\pm 1\%$  of their baseline weight) prior to and following all sessions in the environmental chamber. Data collection during acclimation included rectal temperature ( $T_{re}$ ) and heart rate (HR). The acclimation process was determined to be complete by day 7, as there were no significant changes in final  $T_{re}$  or HR from day 6 to day 7. To familiarize the subjects with the questionnaires to be used during the subsequent STEPO tests, ratings of perceived exertion (RPE; 1) and of thermal sensation (TS; 6,13), were also collected (see Appendix A for the RPE and TS chart).

## STEPO TESTS

### Test Schedules, Measurements and Environmental Conditions

For the STEPO tests, the subjects were divided into two groups. The purpose of this was to test only 1 or 2 subjects per treadmill (on two large treadmills), and to allow

at least one day of recovery between tests for each subject. The STEPO tests were conducted in three environments to include a range of conditions in which STEPO users might work, and to provide data from three environments (to add to the 1999 STEPO data at 38°C or 100°F) to use in prediction modeling. The 3 test environments, all with minimal wind of  $\leq 2$  mph were:

- HOT: dry bulb temperature ( $T_{db}$ ) 32.2°C (90°F) / 30% rh, WBGT 23.4°C (74°F);
- MODERATE:  $T_{db}$  23.9°C (75°F) / 40% rh, WBGT 18.1 °C (64.5°F); and
- COOL:  $T_{db}$  15.6°C (60°F) / 50% rh, WBGT 11.8 °C (53°F).

The order of testing was counterbalanced for the two groups, so that no environment would have an advantage or disadvantage based on test order. Group one, subjects (Ss) 2,6, and 7, tested in STEPO first in the HOT, then MODERATE, then COOL environments, followed by a HOT make-up test for Ss 2 and 7. The test order for group two, Ss 1 and 3, was COOL, HOT, then MODERATE.

During all STEPO tests, core temperature ( $T_{re}$ ) was measured with a flexible thermistor probe (Yellow Springs Instruments), inserted  $\sim 10$  cm beyond the anal sphincter. Four-point skin temperature ( $T_{sk}$ ; chest, arm, calf, thigh) was measured using a thermocouple skin harness. Heart rate was measured via an electrode chest band and digital monitor (Polar). Rectal and skin temperatures were recorded and stored each minute via a data acquisition system (Hewlett Packard). Mean weighted skin temperature was calculated from the four skin temperatures (11); where:  $T_{sk} = 0.3 T_{chest} + 0.3 T_{forearm} + 0.2 T_{thigh} + 0.2 T_{calf}$ . Heart rate was manually recorded every 5 minutes.

A Physiological Strain Index (PSI), calculated from  $T_{re}$  and HR (9), was used to assess the relative level of physiological strain using a scale from 1 to 10. The subjects were also asked to rate their perception of effort (RPE) and thermal sensation (TS) once during each rest and each exercise period. Pre- and post-test questionnaires were also completed for each subject for each test. See Appendix A for RPE and TS scales and pre- and post-test questionnaires.

Pre- and post-test undressed and dressed weights were measured to document hydration status. To assure that the subjects were fully hydrated at the beginning of each test, they were given 500 ml of water or commercial sport drink to drink during the hour prior to testing. As during heat acclimation, body weight was within 1% of baseline weight before each test. Once they entered the environmental chamber, subjects were not allowed to consume any fluids until they exited the chamber when their test was over. This restriction was in accordance with the regulations for STEPO wear.

## STEPO and PICS Equipment

Each test day the subjects wore the STEPO system with rebreather and PICS cooling. They wore their personal underwear and neoprene booties with polypropylene liners and PICS long-sleeved shirt under the STEPO shell. The STEPO system includes an impermeable suit encapsulating the entire body. The STEPO outer shell is

a one-piece garment with integral booties, back pod (to enclose backpack re-breather), visor, airtight closure, exhaust valves, pass through, support harness and glove assembly worn with Toxic Agent Protective over-boots. The material is light in weight and color, is flexible, and is composed of PTFE (Teflon™) and NOMEX™. The fabric has an integrated monomer film which helps decay static charge across the surface. The visor, incorporated into the head portion of the suit, provides a wide field of vision. The visor is a multi-laminate film consisting of a 10 mil fluorinated ethylene polypropylene (FEP) film which is machine laminated to a 7-10 mil hydrophilic film. The FEP is permanently welded to the suit. The hydrophilic film provides anti-fogging. The gloves (viton butyl) for the system are interchangeable, depending on the chemical hazard. (Butyl rubber gloves with cotton liners were worn for these tests.) The weight of the STEPO shell is 12 kg.

Respiratory protection was provided by use of a self-contained breathing apparatus, with a maximum 4-hr capability. The weight of the STEPO breathing system, carried as a backpack under the STEPO shell, is 15 kg. The closed-circuit re-breather circulates exhaled air through a CO<sub>2</sub> scrubber. The effluent is mixed with an O<sub>2</sub> stream supplied from a compressed air bottle, and is then reintroduced into the respirator face piece where it is inhaled. The re-circulated air is cooled by passing over a frozen gel tube before re-breathing.

The PICS system pumps chilled water through the tubing system of a long-sleeved upper body cooling garment worn next to the skin, providing a nominal 150 watts of cooling in a 35°C environment, with the ice bottle changed every 30 min (during each rest period). The PICS, liquid reservoir, pump, and battery supply were carried by the user, supported by a waist belt system with integral hook, and strapped to the outside of the thigh. Use of the PICS system adds approximately 5 kg to the STEPO system weight for a total carried weight of 32 kg. Coolant flow rates as well as inlet and outlet temperatures (to and from the PICS shirt) were measured to document cooling provided during each test. The PICS microclimate cooling units (adjustable to high, low, or off) were set at and remained at HIGH for each subject for each test. The individual cooling rates are listed in Appendix B, Table 5. Mean cooling rates are shown in Table 3.

### **Statistical Treatment**

Statistical analyses included one-way (trial) analysis of variance (ANOVA) to compare the data for test time, dehydration, and cooling rates, and two-way (trial by time) ANOVA to compare T<sub>re</sub>, T<sub>sk</sub>, HR, PSI, RPE, and TS, data among the three test environments. Significance was accepted at the 95% (p<0.05) level of probability. The statistical comparisons of data from the three test conditions are secondary to the primary purpose of the study, which was to determine how long, up to 4 hrs, the volunteers could continue in any of the test environments. Statistical analyses for this report were performed on data through 120 min because this was the last time when all five test subjects were still testing. After 120 min, subjects began to drop out, or were

removed from testing for reasons related to heat strain and/or discomfort (see Appendix C).

Eight male soldier volunteers were originally cleared to participate in this study. Seven volunteers completed preliminary testing; six began the STEPO tests; and five completed the STEPO tests for this study. One volunteer was unable to participate in any testing due to an unrelated accident prior to the start of the study, and subsequent disqualification. Another volunteer was unable to test in any of the three STEPO tests due to an unrelated medical condition and disqualification that occurred after he completed the preliminary tests. A third volunteer withdrew from the study after he completed two of the three STEPO tests. All reported results are for the five volunteers who completed all three STEPO tests.

## RESULTS

The mean (SD) time-weighted metabolic rate for the five test subjects averaged 342 (49) W and is presented in Table 2 along with the individual resting, exercising, and time-weighted data. The time-weighted mean was calculated from resting and exercise metabolic rates with a weighting of 1 to 2, as subjects spent 20 min of each hour at seated rest, and 40 min of each hour walking on the treadmill. The overall mean energy expenditure is the time-weighted mean. The mean (SD) endurance times,  $T_{re}$ ,  $T_{sk}$ , HR, PSI, RPE, TS and percent dehydration are shown in Table 3 (final and overall values) and Table 4 (120 min values). The criteria for stopping a test, and a summary of reasons that subjects were stopped if they did not complete the full 4 hrs are included in Appendix C. Two of 5 subjects were able to complete 4 hrs in the HOT environment; 3 of 5 completed 4 hrs in the MODERATE environment; and 4 of 5 completed 4 hrs in the COOL environment. Two of the volunteers (National Guard soldiers) were able to complete 4 hrs in each environment. However, they were also experiencing heat strain and dehydration (described below).

**Table 2. Metabolic Rates (W) in STEPO with PICS**

Subject	Rest	Exercise	Time-Weighted Mean
1	160	559	426
2	112	450	337
3	110	409	309
6	118	435	329
7	105	409	308
Mean (SD) (n=5)	121 (22)	452 (62)	342 (49)

During the first STEPO test (HOT environment, subjects 2,6,7), it was noted that the PICS ice packs had not been thoroughly frozen, and that there was no ice left at the ice pack changes every rest period (every 30 min). For this reason, Ss 2 and 7 completed make-up tests in the HOT environment. Subject 6 did not do the make-up test (Appendix C). The data from the make-up test for Ss 2 and 7, and from the original test for S6, have been used for comparison and are reported in the HOT test results.

**Table 3. MEAN (SD, n=5) Test Times, Final Values ( $T_{re}$ , HR, PSI,  $T_{sk}$ , RPE, TS), and Overall Values (Dehydration, PICS cooling)**

Variable	HOT	MODERATE	COOL
<b>Test Time (min)</b>	178(57)	223(26)	228(27)
$T_{re}$ ( $^{\circ}$ C)	38.37 (0.46)	37.63(0.34)	37.46 (0.24)
HR (bpm)	164 (14)	122 (11)	108 (7)
PSI (1-10)	6.9 (1.3)	3.6 (0.7)	3.2 (0.4)
$T_{sk}$ ( $^{\circ}$ C)	35.03 (0.78)	31.16 (1.35)	27.18 (1.06)
RPE (6-20)	15.8 (2.3)	13.6 (0.9)	12 (1.6)
TS (0-8.5)	6.4 (0.7)	5.4 (1.3)	3.9 (1.2)
Dehydration (%)	1.83 (1.35)	0.78 (0.65)	0.54 (0.20)
<b>PICS Cooling (W)</b>	304 (36)	247 (29)	193 (27)

Note that final values represent different test times for each subject for each test and, for this reason, were not used for statistical comparison.

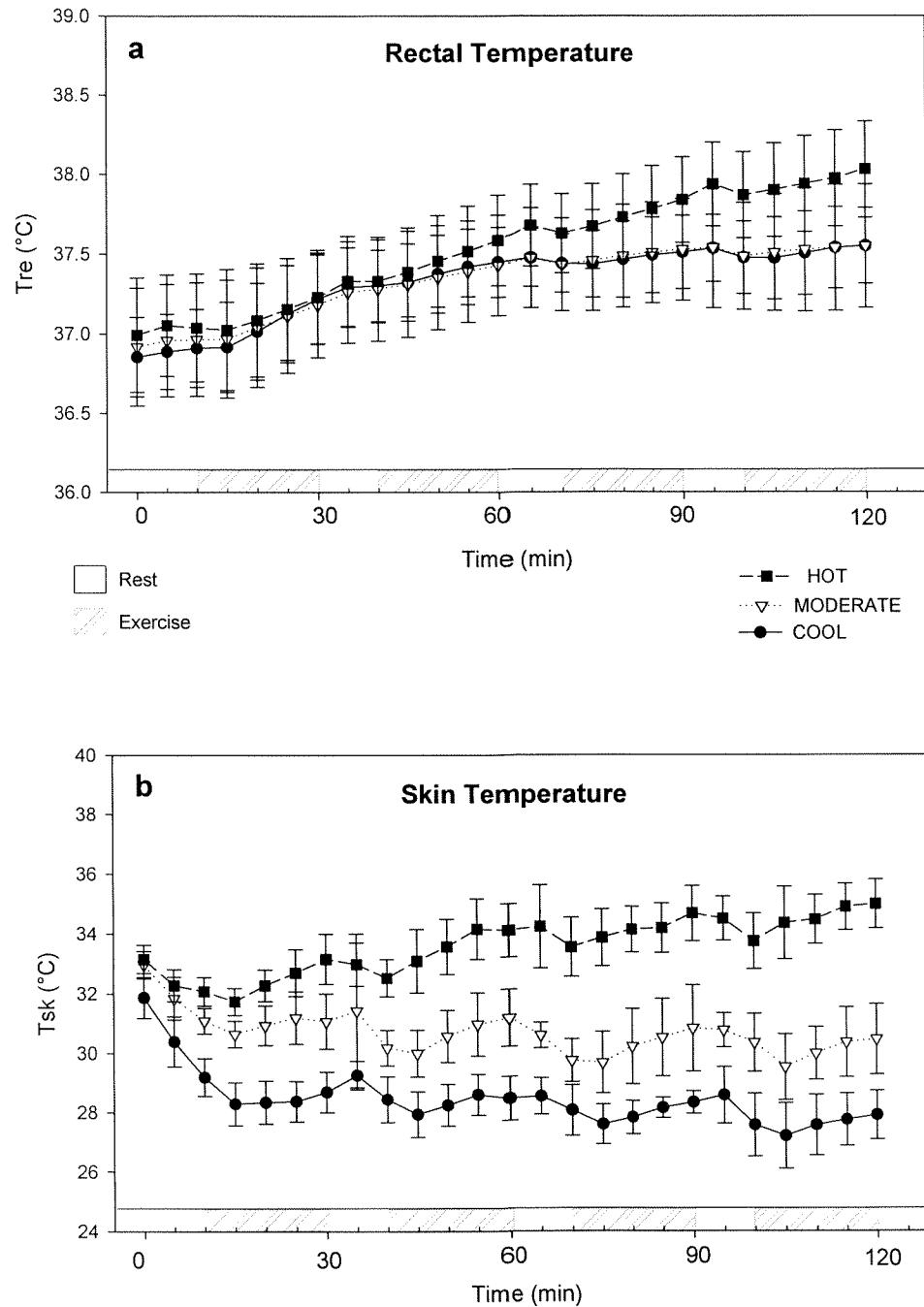
**Table 4. MEAN (SD, n=5) Values at 120 min:  $T_{re}$ , HR, PSI,  $T_{sk}$ , RPE, TS**

Variable	HOT	MODERATE	COOL
$T_{re}$ ( $^{\circ}$ C)	38.03 (0.30)	37.55 (0.39)	37.55 (0.24)
HR (bpm)	143 (19)	112 (9)	100 (8)
PSI (1-10)	5.4 (0.9)	3.2 (0.4)	2.9 (0.4)
$T_{sk}$ ( $^{\circ}$ C)	34.98 (0.82)	30.45 (1.19)	27.90 (0.82)
RPE (6-20)	14.2 (1.3)	12.4 (0.9)	12.2 (1.3)
TS (0-8.5)	6.5 (0.7)	4.9 (0.7)	3.9 (1.5)

Statistical comparisons (p<0.05, n=5) among the three environments for data at 120 min (115 min for RPE and TS):

$T_{re}$	HOT>MODERATE, COOL
HR	HOT>MODERATE, COOL
PSI	HOT>MODERATE, COOL
$T_{sk}$	HOT>MODERATE, COOL
RPE	NS
TS	HOT>COOL (MODERATE: NS)

**Figure 1.  $T_{re}$  and  $T_{sk}$  during all three STEPO trials**

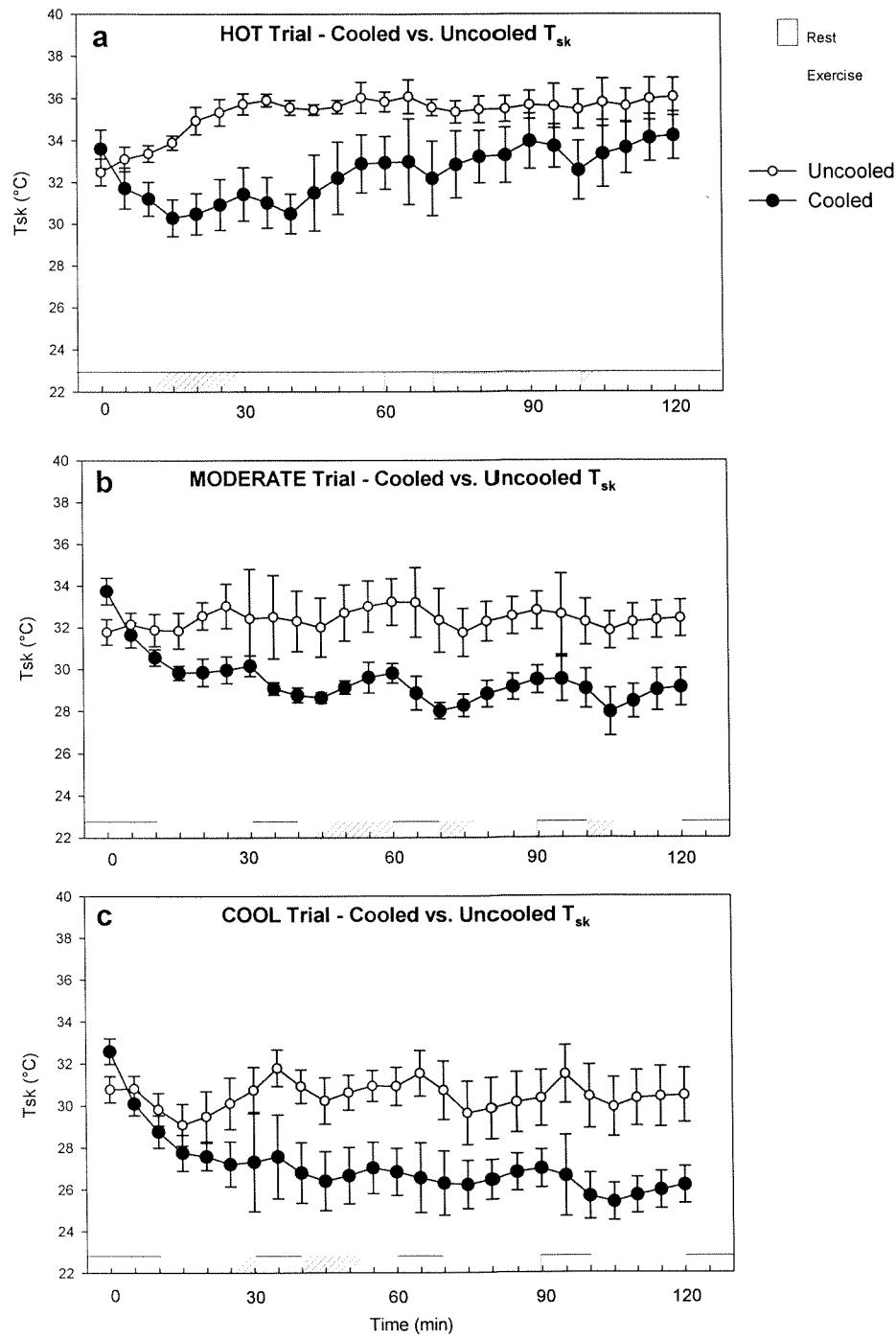


Mean ( $\pm$ SD,  $n=5$ ) rectal and mean weighted skin temperatures are shown in Figures 1a and 1b. By 55 min and through 120 min (while all 5 subjects were still testing),  $T_{re}$  was significantly higher ( $p<0.05$ ) during the HOT test than during the MODERATE and COOL tests. As seen in Figure 1a,  $T_{re}$  during the HOT test continues rising, while in the MODERATE and COOL tests it reaches a plateau. In Figure 1b, mean weighted skin temperatures from 10 through 35 min are significantly higher in the HOT and MODERATE tests than those in the COOL test. By 40 min and throughout the remainder of the 120 min, there are significant differences among all three trials.

In the HOT trial,  $T_{re}$  increased significantly over time from 25 min on, with increases within the exercise cycles and from one cycle to the next. In the MODERATE and COOL trials, there were significant increases at 120 min from 60 and from 55 min, respectively, but no other differences after the first hour. Also, the peak  $T_{re}$  in each of the two earlier exercise bouts was significantly higher than the resting or early exercising values in those bouts. The average  $T_{re}$  increase from 3 to 4 hours was 0.41°C for the two subjects who were able to complete 4 hrs in the HOT trial. For the three subjects who were able to complete 4 hrs in the MODERATE trial,  $T_{re}$  increased 0.10 °C. For the four subjects who were able to complete 4 hrs in the COOL trial,  $T_{re}$  did not increase at all, but decreased 0.01 °C, or essentially did not change during the last hour of testing.

In the HOT trial, the highest  $T_{sk}$ , at 115 and 120 min, were significantly higher than  $T_{sk}$  from 0 thru 45 min only.  $T_{sk}$  at 90 min was significantly greater than  $T_{sk}$  35 min and lower values. There were no significant increases within any of the exercise cycles. In the HOT trial, after the drop during the first 15 min of each cycle (to include the ice-pack change at the 10 min rest),  $T_{sk}$  increased during exercise, never to return to the previous low value. In the MODERATE and COOL trials, the warmest  $T_{sk}$  were early in the trials. In the MODERATE trial, the second bout peak at 35 min was significantly greater than the dips in  $T_{sk}$  at 75 and 105 min. The next highest  $T_{sk}$  at 60 min was not significantly different than any subsequent value. In the COOL trial,  $T_{sk}$  at min zero was significantly higher than all but the 5 min value. The lowest  $T_{sk}$  at 105 min, was significantly lower than the early values at 10, 35, 5, and 0 min. The small peak in  $T_{sk}$  at 35 min, just prior to or during the ice pack change, was greater than the ending values at 100, 110 and 105 min. The downward trend in  $T_{sk}$  during the MODERATE and especially in the COOL trials suggest over-cooling which, in turn, may lead to peripheral vasoconstriction. Vasoconstriction would negate the benefit of the microclimate cooling, as reduced skin blood flow would impair transfer of heat to the environment. In each test in this study, all PICS units were set to high to control variability. In the field, workers would adjust the cooling to their comfort, possibly setting the PICS to low, or intermittently turning the unit on and off. If this occurs, cooling could be enhanced as the cooling medium would be removing heat from warmer skin (4).

**Figure 2. Cooled vs. Uncooled  $T_{sk}$  during all three STEPO trials**



Mean ( $\pm$ SD, n=5) cooled (mean of forearm and chest) and uncooled (mean of thigh and calf)  $T_{sk}$  are shown for HOT (Figure 2a), MODERATE (Figure 2b) and COOL (Figure 2c) Trials. In all three trials, after the first few data points (by 10 min in the HOT, by 35 min in the MODERATE, and by 25 min in the COOL trials) and throughout the 120 min analysis period, un-cooled  $T_{sk}$  were significantly warmer than the cooled  $T_{sk}$ .

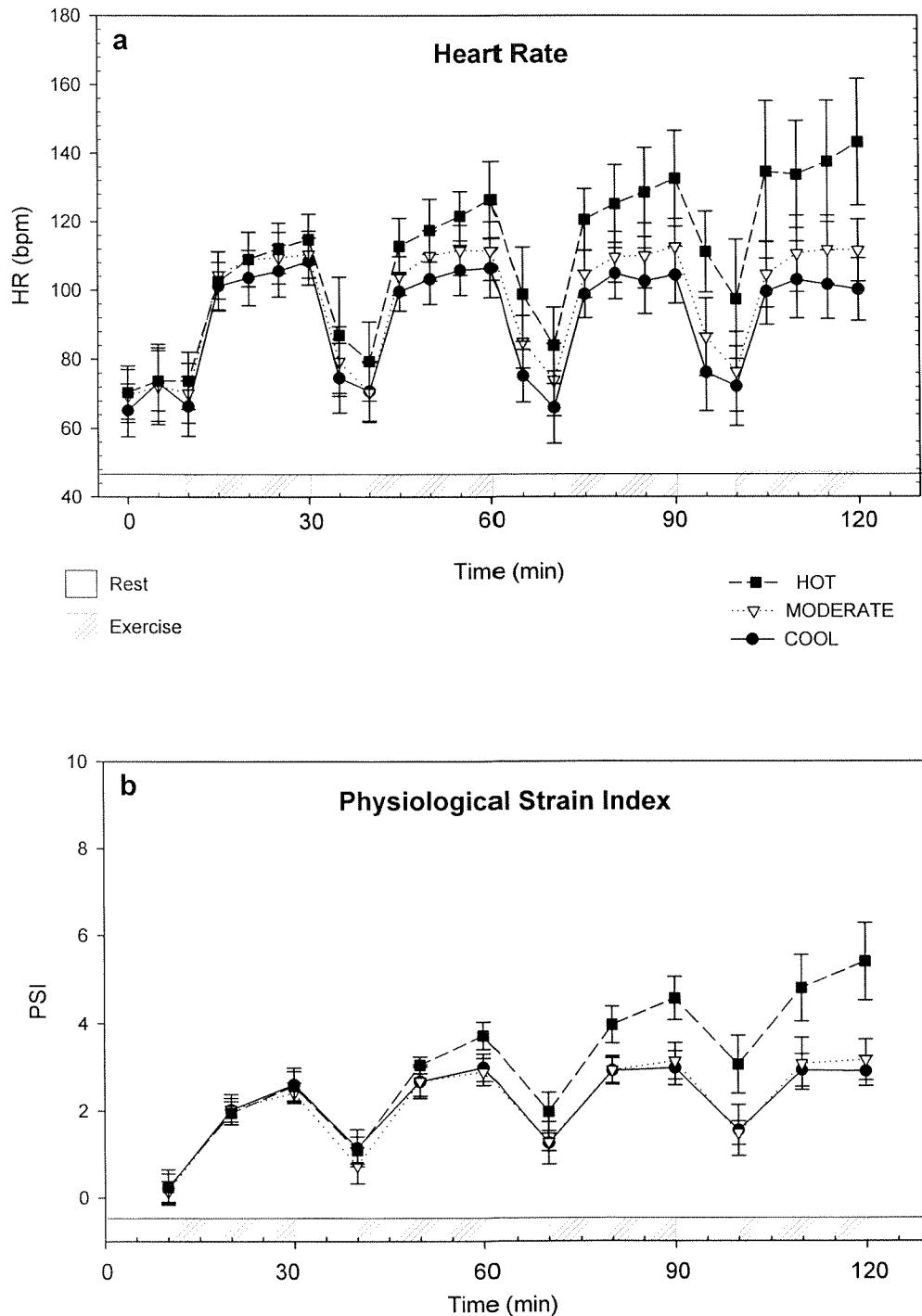
Only in the MODERATE trial were there any non-significant differences in  $T_{sk}$  (between cooled and uncooled skin) after the early minutes; these were minutes 90, 95, 100, and min 120. Cooling immediately significantly lowered  $T_{sk}$  during the first 10 min.

In the HOT trial, once the PICS cooling is established (by ~ 10 min), cooled  $T_{sk}$  at 70, 50, and earlier are significantly lower than the highest  $T_{sk}$  values at 115 and 120 min. Increases in  $T_{sk}$  indicate that cooling may be insufficient. Within the exercise cycles, the increases in cooled  $T_{sk}$  values from 40 to 60 min and from 70 to 90 min were statistically significant. For the uncooled  $T_{sk}$ , there were no further significant differences after the initial increase from the 0-15 min values. Persistently high  $T_{sk}$  of 35.5-36.1°C were observed from 30-120 min.

In the MODERATE trial, for the cooled  $T_{sk}$ , after the initial drop in from 0-10 min, the remaining  $T_{sk}$  are unchanged (33.7, 30.2, 29.8, 29.5 and 29.1 °C at 0, 30, 60, 90 and 120 min, respectively). There are no significant differences for the uncooled  $T_{sk}$  values in the MODERATE trial.

In the COOL trial, the cooled  $T_{sk}$  early in the test at mins 0-35 were significantly warmer than the 105 min cooled  $T_{sk}$ . Once the PICS had cooled the initially uncooled skin, temperatures did not change significantly though they continue a downward trend (32.6°, 27.3°, 26.8°, 26.9° and 26.2°C at 0, 30, 60, 90 and 120 min, respectively), indicating there may be too much cooling. The uncooled  $T_{sk}$  remained unchanged 30.3-30.9°C) except for differences between the lowest value at 15 min vs. the highest values at 35, 65 and 95 min (also 15 and 20 min values less than 35 min value).

**Figure 3. HR and PSI during all three STEPO trials**



Mean ( $\pm$ SD, n=5) HR (Figure 3a) and PSI (Figure 3b). From 0 through 50 min there were no significant differences in either HR or PSI among the three trials. Beginning at 55 min, HR during the HOT trial were significantly higher than during the COOL trial. From 75-120 min, HOT trial HR were significantly higher than HR in

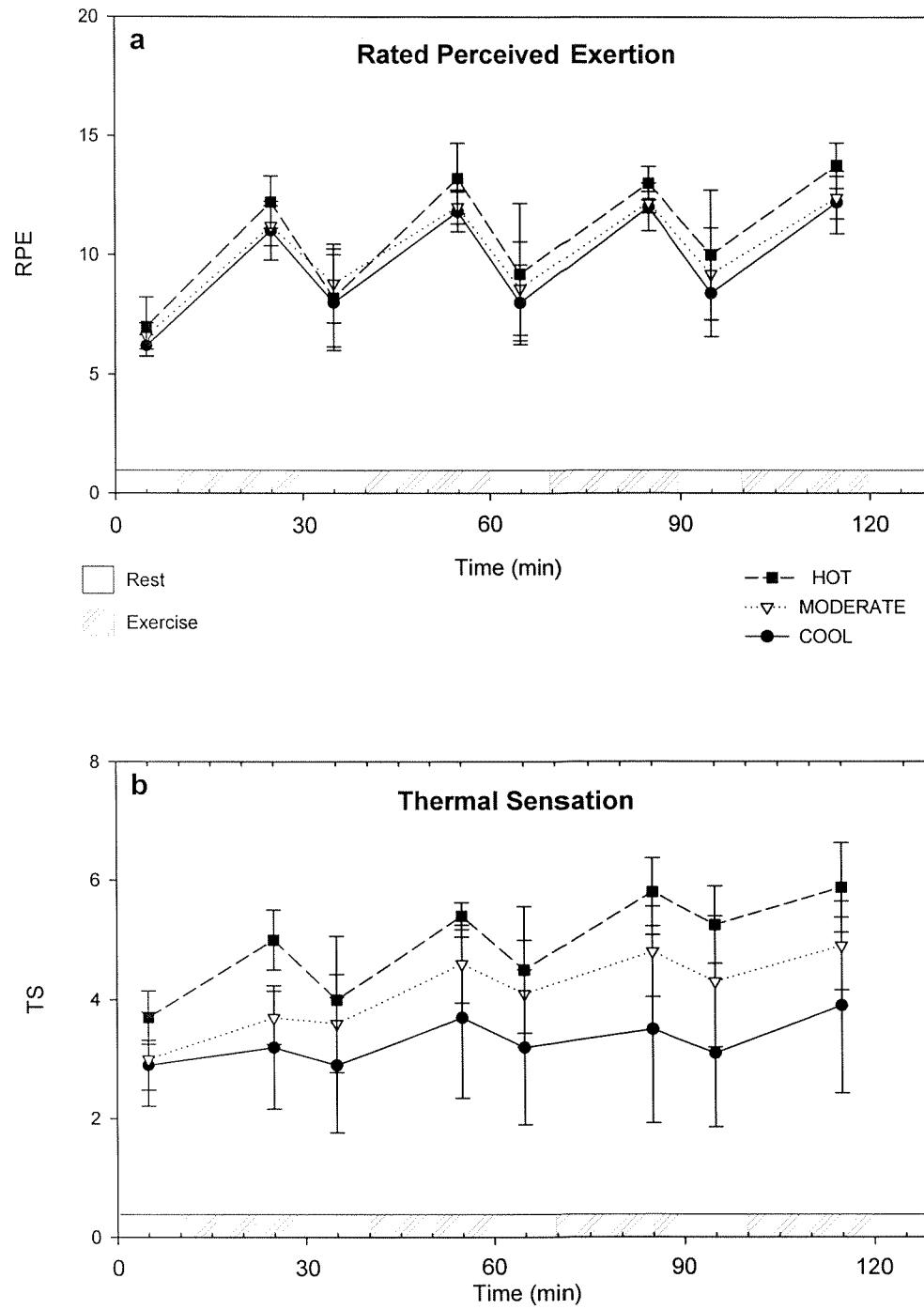
MODERATE and COOL trials. For PSI, analyzed every 10 min, values for the HOT trial were significantly greater than values for both the MODERATE and COOL trials from 60-120 min.

In the HOT trial, the peak HR at 120 min was significantly higher than exercise HR in the first two cycles. The peak HR in the third cycle, at 90 min, was significantly higher than exercise HR in the early part of that cycle and than 50 min and earlier values. These data indicate an upward trend in HR through the 120 min time when all 5 subjects were still testing. At 60 and 30 min, HR were higher than resting values. In the MODERATE and COOL trials, the only significant differences were between exercising and resting values; HR did not increase over time.

The Physiological Strain Index (PSI) is an index calculated from baseline and exercising  $T_{re}$  and HR (9). The index is numbered from 0 to 10 with verbal cues; 1 representing no or little strain, 3 is low strain, 5 is moderate strain, 7 is high strain, and 9 is very high strain. The PSI is used to summarize heat strain for safety purposes, in the field or at the test site. The final PSI values in the current study ranged from 5.5 to 8.8 for the HOT tests (moderate to very high strain), from 2.7 to 4.6 for the MODERATE tests (low to moderate strain), and from 2.8 to 3.8 for the COOL tests (low strain).

PSI values during the HOT trial show significant increases in peak values from each exercise cycle to the next (120>90>60>30 min). All exercise PSI are higher than resting values. For the MODERATE and COOL trials, the 120 min PSI is greater than only the earliest exercise values (30 and 20 min for MODERATE and 20 min for COOL trials). In both MODERATE and COOL trials, the exercise PSI are higher than the resting values. In the body's attempt to remove heat from the body core to the environment, increased peripheral vasodilation exacerbated the effect of the exercise on HR. Conditions in the HOT trial (90°F, uncompensable heat strain) place excessive cardiovascular strain on workers in STEPO. In the MODERATE and COOL conditions, PSI plateaus, indicating heat strain is not limiting work in these conditions.

**Figure 4. RPE and TS during all three STEPO trials**



Mean ( $\pm$ SD, n=5) RPE and TS are shown in Figures 4a and 4b. Subjectively, based on their Rated Perceived Exertion selections, the subjects felt they were working hard to very hard by the end of their HOT tests, and somewhat hard for their MODERATE and COOL tests. Based on their Thermal Sensation selections, the subjects felt hot to very hot by the end of the HOT tests, warm to hot by the end of their

MODERATE tests, and comfortable at the end of the COOL tests (see the end of Appendix A for the RPE and TS questionnaires, and see Table 3 for the data).

In all the trials, the subjects' perceptions of effort were greater during treadmill walking as opposed to seated rest: somewhat to very hard during exercise, and very, very light to light during rest. There were no significant differences among the exercising RPE values, nor among the resting values, indicating changes over time were not significant. There were also no significant differences in RPE among trials.

In the HOT trial, the highest TS values during exercise (mins 115 and 85) were significantly greater than the lowest resting values (mins 65, 35 and 5). Also, min 25 TS was greater than min 5 TS. In the MODERATE trial, only at min 115 was TS greater than at mins 25, 35, and 5; TS at min 55 was also greater than at min 5. In the COOL trial, none of the TS values were significantly different. The TS values were higher during HOT vs. COOL trials at each time measured except at 5 and 35 min. The MODERATE trial TS values were generally not significantly different from either the HOT or COOL trial values except at min 85 and 95 where they were also greater than the COOL trial TS values.

## DISCUSSION

In general, physiological responses in the HOT environment were significantly different than responses in the MODERATE and COOL environments, which were similar. While responses to the HOT environment (90°F) in the current study were less severe than those reported for 100°F (2), and the test times were extended (178 min at 90°F, compared to ~90 min at 100°F), we would still advise that a 4-hr work time at 90°F is too long. However, STEPO users working in a 90°F environment may be able to tolerate 150 min work times at the metabolic rates tested in this study. In the MODERATE and COOL environments, heat strain should not affect performance time up to 4 hrs. The average test times for the MODERATE and COOL tests in this study were 223 min and 228 min, respectively (Table 3). Two volunteers in the HOT tests were removed from testing due to heart rates that reached the study criteria levels (90% of age estimated maximum for 5 min or a one-time reading of 95% of age estimated maximum). Two volunteers, one of the experienced users and one inexperienced, used their reserve O<sub>2</sub> beyond the low O<sub>2</sub> alarm by 180 min in the MODERATE and COOL environments, indicating the work of breathing may be a limiting factor. We did not see low O<sub>2</sub> levels during the HOT tests. Most of the test subjects reported feeling very tired and weighed down by the STEPO system (Appendix C).

As seen in previous STEPO studies, dehydration remains a problem. In the current study, we observed body fluid losses averaging less than 1% in the MODERATE and COOL conditions, but almost 2% in the HOT condition. Dehydration of 2% can have a negative affect on performance, and greater dehydration limits performance and increases the risk of heat casualties (12). As long as workers in

STEPO have no access to drinking fluids for the time they are encapsulated, some dehydration is unavoidable, especially in warm and hot environments. Individual values for the two test subjects who completed 240 min in the HOT environment were 3% and 3.5% dehydration (Table 3). Though these two individuals were able to complete 240 min in the chamber, their temperatures were 38.89°C and 38.25°C, respectively. Any  $T_{re}$  of greater than 38.3°C may be associated with diminished performance (8). In addition, one other subject had a  $T_{re}$  of 38.67°C at 142 min in the HOT chamber, his final time in this environment. Primarily for these reasons, we would not recommend allowing a 4-hr work time in a 32.2°C (90°F) environment. In contrast, none of the test subjects'  $T_{re}$  exceeded 38°C in the MODERATE or COOL conditions.

## CONCLUSIONS / RECOMMENDATIONS

In the 90°F environment, subjects wearing STEPO with shirt only PICS continued to exhibit uncompensable heat strain; the micro-environment did not allow removal of heat from the body. The observation of peripheral vasodilation (evidenced by very warm skin temperatures) showed an unsuccessful attempt by the body to dissipate heat from the core to the skin to the environment, resulting in no outlet for release of heat. Increasing skin temperatures, both under the cooling shirt and especially for uncooled skin, resulted in a high core temperature and a high level of cardiovascular strain for workers wearing STEPO. The 75°F and 60°F environments had less of an impact than did the 90°F environment. At these MODERATE and COOL conditions, thermal strain should not limit mission completion at the metabolic rates employed in the present study (and measured in the field; 3). In the MODERATE environmental condition, core temperatures plateaued after about 150 min. For the three subjects who were able to complete the 4-hr 75°F trial, we did observe a 0.10°C increase in  $T_{re}$  during the last hour. This increase is within acceptable limits and should not interfere with completion of a 4-hr mission. Heart rates in the both the MODERATE and COOL environments did not approach age-estimated physiologic limits, even for the subjects who were able to complete the 4-hr trials. Physiological Strain Index data reflect these trends, indicating that thermal strain should not be the limiting factor in completion of 4-hr missions in 75°F and 60°F environments. These data support a safe work time of 2.5 hours at 90°F and 4-hr work times at 75°F and 60°F.

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**APPENDIX A**  
**STUDY QUESTIONNAIRES**

**ENTRANCE INTERVIEW****QUESTIONS TO ASK EACH SUBJECT UPON ARRIVAL FOR STEP0 TESTING:**

1. How do you feel? \_\_\_\_\_
2. Do you have any muscle or joint pain or soreness, especially in your legs, back or neck?  
\_\_\_\_\_
3. Was your urine darker than usual (dark yellow)?  
\_\_\_\_\_
4. Did you adhere to the study restrictions? \_\_\_\_\_
5. Do you have any questions or complaints?  
\_\_\_\_\_
6. Are you still willing to participate in this study?  
\_\_\_\_\_

Entrance Interviewer's initials / date / time 

If subject doesn't feel well, has muscle or joint pain, did not adhere to study restrictions (re medications or other health related issue), consult the covering physician and notify PI. If subject does not want to continue testing, notify PI.

Physician's Comments/Decision: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_Covering Physician's initials / date / time If needed: additional comments on reverse

U.S. ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Thermal and Mountain Medicine Division

Kansas Street, Natick, Massachusetts 01760-5007

Study Name: Self Contained Toxic Environment Protective Outfit (STEPO) with Personal Ice Cooled

Microclimate Cooling System in Three Environments

USARIEM Study #: H01-04 (HSRRB Log #: A-11159)

Principal Investigator: Leslie Levine

SUBJECT #

DATE

(ddmmyy)

TEST CONDITIONS (Temp/%rh)

---

## POST-TEST EXIT QUESTIONNAIRE

---

**4 HOUR TEST COMPLETED\***

OR

**Reasons for Ending the Test Before 4 Hours**

**Test Ended by Study or Medical Staff Due To\*:**

Tre Limit  HR Limit

Equipment Failure

Other Reason:

---

**Test Ended by Volunteer Due To:** (\*Ask the volunteers the following questions after any test, whether or not they completed the 4-hr test, whether or not their test was ended by study staff. Completed info above will make it clear on this questionnaire who ended the test and why.)

Felt too hot

Felt exhausted overall

STEPO system felt too heavy

Backpack felt too heavy

Had difficulty breathing

Breathing air felt too hot

Back was tired or sore

Legs and/or feet were tired or sore

Felt too confined or closed-in (claustrophobic)

Other Reason

---

**Any Additional Comments:**

---

Exit Interviewer's initials / date / time

If needed, add additional comments on reverse

Rated Perceived Exertion

6  
7 Very, Very Light  
8  
9 Very Light  
10  
11 Fairly Light  
12  
13 Somewhat Hard  
14  
15 Hard  
16  
17 Very Hard  
18  
19 Very, Very Hard  
20

Thermal Sensation

0.0 Unbearably Cold  
0.5  
1.0 Very Cold  
1.5  
2.0 Cold  
2.5  
3.0 Cool  
3.5  
4.0 Comfortable  
4.5  
5.0 Warm  
5.5  
6.0 Hot  
6.5  
7.0 Very Hot  
7.5  
8.5 Unbearably Hot

## APPENDIX B

### INDIVIDUAL DATA

**Table 5. Individual Values: Test Time (min), Final  $T_{re}$  ( $^{\circ}$ C), HR (bpm), PSI (1-10),  $T_{sk}$  ( $^{\circ}$ C), RPE (6-20) / TS (0-8.5), Overall Dehydration (%) and Overall PICS Cooling (W)**

Subject #	Variable	HOT	MODERATE	COOL
1  S1 Test Order: Cool Hot Moderate	<b>Test Time</b>	142 min	240 min	180 min
	<b><math>T_{re}</math></b>	38.67	37.97	37.79
	<b>HR</b>	179 (90%)	120	109
	<b>PSI</b>	7.38	2.74	2.94
	<b><math>T_{sk}</math></b>	36.17	32.09	28.04
	<b>RPE / TS</b>	13 / 6	14 / 6.5	14 / 5.5
	<b>Dehydration</b>	1.5	1.28	0.63
	<b>Cooling</b>	362	286	229
2  S2 TEST ORDER: Hot Moderate Cool Hot make-up	<b>Test Time</b>	240 min	240 min	240 min
	<b><math>T_{re}</math></b>	38.89	37.88	37.43
	<b>HR</b>	179	131	101
	<b>PSI</b>	8.84	4.59	2.91
	<b><math>T_{sk}</math></b>	34.06	30.78	27.20
	<b>RPE / TS</b>	18 / 6	13 / 4	12 / 4
	<b>Dehydration</b>	3.02	1.61	0.78
	<b>Cooling</b>	299	247	181
3  S3 Test Order: Cool Hot Moderate	<b>Test Time</b>	240 min	240 min	240 min
	<b><math>T_{re}</math></b>	38.25	37.43	37.27
	<b>HR</b>	162	104	102
	<b>PSI</b>	6.96	3.42	2.77
	<b><math>T_{sk}</math></b>	34.63	29.96	28.38
	<b>RPE / TS</b>	18 / 7.5	13 / 6	11 / 4
	<b>Dehydration</b>	3.46	0.50	0.58
	<b>Cooling</b>	263	207	166

(Table 5 continued on next page.)

(Table 5 continued from previous page.)

Subject #	Variable	HOT	MODERATE	COOL
6 S6 TEST ORDER: Hot Moderate Cool	<b>Test Time</b>	120 min	180 min	240 min
	<b>T<sub>re</sub></b>	37.67	37.14	37.22
	<b>HR</b>	153	125	117
	<b>PSI</b>	5.55	3.55	3.76
	<b>T<sub>sk</sub></b>	35.13	29.97	25.82
	<b>RPE / TS</b>	16 / 6.5	15 / 6.5	10 / 4
	<b>Dehydration</b>	0.62	0.38	0.24
	<b>Cooling</b>	300	261	215
7 S7 TEST ORDER: Hot Moderate Cool Hot make-up	<b>Test Time</b>	150 min	215 min	240 min
	<b>T<sub>re</sub></b>	38.37	37.71 * (37.22 *)	37.61
	<b>HR</b>	148	130 last ex 95 rest (final)	111
	<b>PSI</b>	5.96	3.47	3.46
	<b>T<sub>sk</sub></b>	35.17	33.00	26.48
	<b>RPE / TS</b>	14 / 6	13/4 last ex 6/3 rest (final)	13 / 2
	<b>Dehydration</b>	0.53	0.58	0.46
	<b>Cooling</b>	296	236	174

\* final T<sub>re</sub> for S7/MODERATE test was 37.22°C (but probe had slipped); peaks were 37.71°C from 3 hrs 17 min thru 3 hrs 26 min, and 37.9-38.1°C from 2 hrs 15 min thru 2 hrs 32 min and again at 2 hrs 58 min thru 3 hrs 1 min.

**Table 6. Individual Values at 120 Minutes for  $T_{re}$  ( $^{\circ}$ C),  $T_{sk}$  ( $^{\circ}$ C), HR (bpm), PSI (1-10), RPE (6-20) / TS (0-8.5)**

<b>Subject #</b>	<b>Variable</b>	<b>HOT</b>	<b>MODERATE</b>	<b>COOL</b>
<b>1</b> S1 Test Order: Cool Hot Moderate	$T_{re}$	38.48	37.75	37.77
	HR	169	106	104
	PSI	6.8	2.6	2.8
	$T_{sk}$	36.21	30.02	27.91
	RPE / TS	14 / 6.5	12 / 4.5	14 / 5
<b>2</b> S2 Test Order: Hot Moderate Cool Hot Make-Up	$T_{re}$	37.95	37.67	37.51
	HR	131	111	86
	PSI	4.9	3.3	2.4
	$T_{sk}$	34.35	29.36	28.92
	RPE / TS	13 / 5	12 / 5	12 / 3.5
<b>3</b> S3 Test Order: Cool Hot Moderate	$T_{re}$	37.89	37.25	37.35
	HR	122	100	101
	PSI	4.5	2.9	2.9
	$T_{sk}$	34.13	29.79	28.5
	RPE / TS	15 / 6.5	12 / 5	13 / 5
<b>6</b> S6 Test Order: Hot Moderate Cool	$T_{re}$	37.68	37.06	37.30
	HR	153	119	106
	PSI	5.6	3.2	3.2
	$T_{sk}$	35.13	30.70	27.1
	RPE / TS	16 / 6.5	14 / 6	11 / 4.5
<b>7</b> S7 Test Order: Hot Moderate Cool Hot Make-Up	$T_{re}$	38.15	38.01	37.82
	HR	141	122	104
	PSI	5.1	3.8	3.3
	$T_{sk}$	35.09	32.39	27.09
	RPE / TS	13 / 5.5	12 / 4	11 / 1.5

## APPENDIX C

### REASONS for STOPPING EACH TEST

#### CRITERIA for DISCONTINUING a TEST

Testing was to be stopped for the day for any subject whose  $T_{re}$  reached 39.5°C, or increased faster than 0.6°C within 5 min. No one was removed from testing for  $T_{re}$  limits. Testing was also stopped for the day for any subject whose HR reached 95% of age-estimated maximal (220 minus age), or remained at 90-94% of age-estimated maximal for 5 minutes. Tests were stopped for two subjects in the HOT environment because of heart rate limits. Testing was to be stopped if there was an equipment malfunction. Two tests in the MODERATE environment were stopped by the P.I. due to limited O<sub>2</sub> reserve (indicated by O<sub>2</sub> alarm and confirmed by low pressure readings on the O<sub>2</sub> gauge). In addition, individual subjects were removed from testing at the discretion of the P.I. or the Medical Officer or at the subject's request, whichever came first. Besides the two HR limits and two low O<sub>2</sub> reserves noted, all other tests were ended by requests from the subjects. Details of each individual test are summarized below. In the experience of the investigators (2, 3, 8), besides the occurrence of criteria  $T_{re}$  and HR, their decisions to end a test are often based on observation of an unsteady gait or a test subject reporting feeling lightheaded or nauseated; the subjects' reasons for stopping often include feeling too hot or too tired, feeling lightheaded or nauseated, or having a headache. If physiological measures indicated a subject was not at increased risk, he was allowed to continue even though he was not feeling his best (reported common symptoms of heat stress). However, once the subject decided he did not want to continue, his test for that day was ended.

Only 2 of 5 subjects completed the 240 min test in the HOT environment; 3 of 5 subjects completed 240 min in the MODERATE environment; 4 of 5 subjects completed 240 min in the COOL environment. The subjects' comments following each test were (mostly) in response to the Post-Test Exit Questionnaire (enclosed, Appendix A). In this questionnaire, the volunteers were asked a series of questions after each test, and were encouraged to include their own comments. Also enclosed in Appendix A are the Pre-Test Questionnaire and the Rated Perceived Exertion (RPE) and Thermal Sensation (TS) questionnaires used during testing.

#### HOT ENVIRONMENT TESTS

Subject 1: 142 min test ended by P.I. due to 5-min limit at 90% of age estimated maximal HR. By the end of the test, subject 1 was 1.5% dehydrated.

Subject 1 Comments on the Post-Test Questionnaire: The STEPO system and backpack felt too heavy on his neck; his back and especially his neck felt sore. The breathing air felt too hot after the first hour, and he felt too hot after the 2<sup>nd</sup> ice-pack change (ice-pack changes for the PICS were every 30 min). Subject 1 also said he felt

tired toward the end of the test, and that his feet were tired and there was too much sweat around his feet. He did not feel too confined or closed-in (claustrophobic).

Subject 2: In the first HOT trial (inadequate cooling) the 112 min test was ended by the P.I. due to the 1-time limit of 95% of age-estimated maximal HR. In the make-up trial, subject 2 completed the 240 min test. For the last 5 min of the test he was at 90% of his age-estimated maximal HR, an "end-test" criteria if the test was to go beyond 240 min. Subject 2 was 3% dehydrated after his make-up test (3.1% after his first test).

Subject 2 Comments on the Post-Test Questionnaire (for Make-Up Test): Subject 2 felt too hot, felt STEPO system was too heavy, had difficulty breathing (he said the breathing air almost made him stop at 2 hrs; he felt there was resistance to exhalation on about every third breath), he felt the breathing air was too hot, he felt exhausted overall, and felt the backpack was too heavy. He said he did not feel closed in or confined (claustrophobic), nor did his feet or legs feel tired or sore during the test. He said his feet did feel sore after the test was over.

Subject 3: 240 min test completed. Subject 3 was 3.5% dehydrated by the end of the test.

Subject 3 Comments on the Post-Test Questionnaire: Subject 3 said the cooling system was not good, that he could barely feel any cooling. He said he felt too hot, he felt exhausted overall, the STEPO system felt too heavy after 3 hrs, the backpack felt too heavy the last hour, and that his legs and feet were tired. He said he did not have difficulty breathing, that the breathing air did not feel too hot, that his back was not sore, and that he did not feel confined or closed in (claustrophobic).

Subject 4: SUBJECT 4 WAS NOT INCLUDED IN THE STATISTICAL COMPARISONS OR IN THE REPORTED DATA, AS HE DID NOT COMPLETE ALL 3 TESTS. THIS WAS HIS SECOND TEST. The 30-min test was ended by the volunteer due to discomfort. He said he felt too hot, tired, and that his neck and the top of his back were sore due to pressure from the backpack. He was 0.2% dehydrated.

Subject 4 Comments on the Post-Test Questionnaire: Subject 4 said the backpack felt too heavy on his neck and back, but that the STEPO system did not feel too heavy. He said he had difficulty breathing at the beginning; the breathing air did not feel too hot, but he felt there was not enough air. His legs and feet did not feel sore, and he did feel too confined or closed-in (claustrophobic). He said he did not want to do any more STEPO tests. (He had been scheduled for one more, which he did not do.)

Subject 6: This 120 min test was ended by the subject due to discomfort of the backpack straps; the backpack felt too heavy, and his feet felt like they were in puddles. Subject 6 was 0.6% dehydrated by the end of his test. In this trial, it was determined that cooling was inadequate, but S6 was not able to participate in a make-up test. Following his HOT test, subject 6 said the STEPO fabric was rubbing on the skin behind the left knee, causing a burning sensation. The skin appeared to be irritated.

Consequently S6 wore a neoprene knee brace pad on his left knee. Following his third test, the skin on his lower legs was further irritated, preventing him from participating in the make-up test (per orders of the medical officer).

Subject 6 Comments on Post-Test Questionnaire: He also said he felt too hot, the STEPO system felt too heavy, he had difficulty breathing (especially near the end of his test), the breathing air felt too hot, and he felt confined or closed-in (claustrophobic) by the end of his test.

Subject 7: In the first trial (inadequate cooling) the 91-min test was ended by the subject because he felt too hot, his breathing air felt too hot, and the skin on his lower legs felt burning. In the make-up trial, the 150-min test was ended by the subject because he felt exhausted, and his body was tired and sore. He was 0.5% dehydrated by the end of the 150-min make-up test (1.2% at end of first HOT test).

Subject 7 Comments on Post-Test Questionnaire (for Make-Up Test): Subject 7 said he felt exhausted overall, he felt too hot (though not as hot as his first 90° test which ended at 91 min). He said his head, especially, felt very hot, the STEPO system and the backpack felt too heavy, his back was tired or sore, he felt the breathing air was too hot, and that he had some difficulty breathing. He also felt a bit confined or closed in (claustrophobic) – he thought due to the fogging of the mask/visor. Subject 7 also said the STEPO fabric was rubbing on the skin of his lower legs, causing a burning sensation.

## **MODERATE ENVIRONMENT TESTS**

Subject 1: 240 min test completed. Subject 1 was 1.3% dehydrated by the end of the 4-hr test.

Subject 1 Comments on the Post-Test Questionnaire: Subject 1 said his back, legs and feet were tired or sore, and that the breathing air felt too hot. He said he did not feel too hot or exhausted overall. He also did not feel the STEPO system or backpack were too heavy, nor did he have difficulty breathing. He also did not feel too confined or closed-in (claustrophobic).

Subject 2: 240 min test completed. Subject 2 was 1.6% dehydrated by the end of the 4-hr test.

Subject 2 Comments on the Post-Test Questionnaire: Subject 2 said that his back was tired or sore – but “not more than usual in this type of suit.” He also said his feet were a little sore, and too wet. He commented about the back soreness, saying he thought the pack design needed improvement. He said he needed to re-adjust periodically (loosen at shoulders, tighten at waist, then vice-versa about every half-hour). He said he did not feel that the STEPO system or backpack was too heavy. He also did not feel too hot, too exhausted, or too confined or closed-in (claustrophobic). He said he did not have difficulty breathing, nor did he feel the breathing air was too hot.

Subject 3: 240 min test completed. Subject 3 was 0.5% dehydrated by the end of the 4-hr test.

Subject 3 Comments on the Post-Test Questionnaire: Subject 3 said that the top of the mask loosened, and that he lost oxygen. He said his back, legs, and feet were tired or sore. He did not feel the STEPO system or the backpack were too heavy. He did not feel too hot, too exhausted, or too confined or closed-in (claustrophobic). He did not have difficulty breathing, nor was the breathing air too hot.

Subject 4 did not do a test in the MODERATE environment.

Subject 6: 180 min test ended by the subject due to discomfort. He was 0.4% dehydrated after his 3-hr test.

Subject 6 Comments on the Post-Test Questionnaire: Subject 6 described several areas of irritation/annoyance: from the STEPO fabric at the back of his head, from the air hose on the right side, and from the radio ear-piece, which kept falling out. He said he felt too confined or closed-in (claustrophobic), that his back was somewhat tired or sore, and that by the end of his test, the breathing air felt too hot and he had some difficulty breathing.

Subject 7: The 215 min test was ended by the P.I. due to a suspiciously low  $T_{re}$ . In addition, the  $O_2$  alarm sounded at 3 hrs, indicating a limited time for the  $O_2$  reserve. After exiting the chamber, subject 7 readjusted the  $T_{re}$  probe; subsequent readings indicated the probe had slipped. Subject 7 was 0.6% dehydrated by the end of his test.

Subject 7 Comments on the Post-Test Questionnaire: Subject 7 said he had some discomfort from the STEPO fabric rubbing on his lower leg, left side only. The PICS cooling system was strapped to the right leg, minimizing rubbing. His skin on the left shin was slightly abraded and red on examination after the test. Subject 7 said his feet were mildly sore, with a few "hot spots." He did not feel too hot, confined, or exhausted, nor did he feel the STEPO system or backpack were too heavy. He did not have difficulty breathing nor did he feel the breathing air was too hot.

## COOL ENVIRONMENT TESTS

Subject 1: 180 min ended by the P.I. due to low  $O_2$  in supply tank. The pressure gauge indicated not enough supplemental  $O_2$  to last another rest/exercise cycle. Subject 1 was 0.6% dehydrated by the end of his 3-hr test.

Subject 1 Comments on the Post-Test Questionnaire: Subject 1 did not indicate that he felt too hot, exhausted, or claustrophobic. Neither did he indicate that the STEPO system or backpack felt too heavy, nor that his legs or feet felt tired or sore. He did not indicate that he had difficulty breathing or that the breathing air felt too hot. Subject 1 did comment that the shoulder straps felt like they were "digging in," and that the mask slipped forward as his face became sweat covered.

Subject 2: 240 min test completed. Subject 2 was 0.8% dehydrated by the end of this 4-hr test.

Subject 2 Comments on the Post-Test Questionnaire: Subject 2 said he did not feel too hot, but was comfortable, maybe cool. He said that his back was not more tired or sore than usual, and that the backpack did not feel heavier than usual. He did not feel the STEPO system was too heavy, nor did he have any trouble breathing nor feel that the breathing air was too hot. He did not feel too confined or closed-in (claustrophobic). His legs and feet did not feel tired or sore. He did comment that a strap on top of the cooling shirt felt irritating at his waist. He described the pain like the way cold hands feel in winter, when they come to room temperature. He said the discomfort lasted about a minute or less.

Subject 3: 240 min test completed. He was 0.6% dehydrated by the end of the 4-hr test.

Subject 3 Comments on the Post-Test Questionnaire: Subject 3 did not indicate that he felt too hot, exhausted, or claustrophobic. Neither did he indicate that the STEPO system or backpack felt too heavy, nor that his legs or feet felt tired or sore. He did not indicate that he had difficulty breathing or that the breathing air felt too hot. Subject 3 did comment that the STEPO hood was uncomfortable, that it forced his head to look down/forward. He said the hood was pressing on the back of his head, and was very uncomfortable.

Subject 4: SUBJECT 4 WAS NOT INCLUDED IN THE STATISTICAL COMPARISONS OR IN THE REPORTED DATA AS HE DID NOT COMPLETE ALL 3 TESTS. THIS WAS HIS FIRST TEST. The 90 min test was ended by the volunteer due to discomfort from the  $T_{re}$  probe and the urgent need to urinate. He was 0.7% dehydrated after 1.5 hours.

Subject 4 Comments on the Post-Test Questionnaire: He felt more mentally than physically exhausted. He did not have difficulty breathing, but the mask needed adjusting. He didn't feel too hot, or that the breathing air was too hot, nor did he feel the STEPO system and backpack were too heavy. He did not feel that his back, legs or feet were tired or sore. He felt too confined or closed-in (claustrophobic) only when seated. Subject 4 also commented that the  $T_{re}$  probe was irritating and that the backpack strap pressing on his bladder increased his urgency to urinate.

Subject 6: 240 min test completed. Subject 6 was 0.2% dehydrated by the end of this 4-hr test.

Subject 6 Comments on the Post-Test Questionnaire: Subject 6 said he did not feel too hot, but was comfortable. He said the backpack felt too heavy toward the end of the test, and his back was tired or sore, especially towards the end of the test. He did not feel exhausted or that the STEPO system was too heavy. He did not have difficulty breathing, nor did he feel that the breathing air was too hot. He said he felt a little too confined or closed-in (claustrophobic). He did not feel that the muscles of his legs and

feet were tired or sore, but he did feel that the skin was irritated. The skin behind his knees and on his feet did look irritated. Subject 6 also commented that tape helped greatly when placed on the outside of the STEPO suit to hold the face shield up. (Several of the volunteers complained that the face shield was often pulling forward, pulling their heads down.) He said the face shield fogged up during testing.

Subject 7: 240 min test completed. Subject 7 was 0.5% dehydrated by the end of this 4-hr test.

Subject 7 Comments on the Post-Test Questionnaire: Subject 7 said that he felt too cold during this test. He did not feel exhausted and did not feel the backpack was too heavy. He said the STEPO system felt too heavy for about the last hour. He said his shoulders, but not his back, felt tired or sore. His legs and feet did not feel tired or sore, but his feet felt tender from being wet.